The Fueling of Nuclear Activity: II. The Bar Properties of Seyfert and Normal Galaxies

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ABSTRACT

We use a recent near-infrared imaging survey of samples of Seyfert and normal galaxies to study the role of bars in the fueling of nuclear activity. The active galaxy sample includes Seyfert galaxies in the Revised Shapely-Ames (RSA) and Sandage & Tammann's (1987) extension to this catalog. The normal galaxies were selected to match the Seyfert sample in Hubble type, redshift, inclination and blue luminosity. All the galaxies in both samples classified as barred in the RSA catalog are also barred in the near-infrared. In addition, $\sim 55\%$ of the galaxies classified as non-barred in the RSA show evidence for bars at 2.1 μm. Overall, $\sim 70\%$ of the galaxies observed show evidence for bar structures. The incidence of bars in the Seyfert and normal galaxies is similar, suggesting Seyfert nuclei do not occur preferentially in barred systems. Furthermore, a slightly higher percentage of normal galaxies have multiple-bar structures.

A significant percentage of the Seyfert galaxies in our sample show no evidence for the presence of a bar even in the near-infrared. This suggests that either large-scale kiloparsec bars are not a universal fueling mechanism in Seyfert galaxies or that the bars in the non-barred Seyferts were recently destroyed, possibly by the formation of the central black hole.

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1. Introduction

Galactic bars are frequently invoked as candidates for facilitating the transfer of mass from the interstellar medium of Seyfert galaxies to their central engines (e.g. Schwartz 1981; Norman 1987; Shlosman, Frank & Begelman 1989). However, the importance of bars in Seyfert galaxies remains controversial, with some studies suggesting that Seyfert nuclei occur preferentially in barred systems (e.g. Arsenault 1989), while others find no such preference (Heckman 1980; Simkin, Su, & Schwarz 1980; Moles et al. 1995). Most comparisons of the hosts of normal and active galaxies have been made at optical wavelengths, where the effects of dust and star formation can mask bar structures. Near-infrared images provide a better tracer of the mass distribution including bars since the relative importance of these effects is reduced at near-infrared wavelengths. Several K-band imaging studies of Seyfert galaxies have revealed the presence of bar structures in galaxies classified as unbarred in the optical (e.g. Scoville et al. 1988; Thronson et al. 1989; McLeod & Reike 1995), demonstrating the benefit of working in the near-infrared. In this *Letter*, we use a recently completed modified K-band imaging survey of samples of Seyfert and normal galaxies (Mulchaey, Regan & Kundu 1997; hereafter Paper I) to study the role of bars in the fueling of nuclear activity.

2. Sample Selection and Bar Identification

The Seyfert sample was selected from the Revised Shapely-Ames (RSA) and the Sandage & Tammann (1987) extension to the RSA. All of the galaxies observed have recessional velocities less than 5000 km s^{-1} and logarithmic axial ratios (Log a/b) less than 0.2. The axial ratio limit was adopted to avoid highly inclined galaxies where bars can be difficult to recognize. The control sample of normal galaxies was also selected from the RSA and was matched to the Seyfert sample in Hubble type, redshift, inclination and blue luminosity. A total of 30 Seyfert and 25 normal galaxies were observed in the near-infrared with a modified K-band filter. A complete description of the sample properties and observing conditions are given in Paper I.

The bar morphology of each galaxy was determined using the criteria outlined in detail in Paper I. Approximately 50% of the galaxies in both samples are classified as

barred in the RSA catalog. We detect near-infrared bars in all of these galaxies. We also find evidence for bars in sixteen of the twenty-nine galaxies classified as unbarred in the RSA. This further demonstrates the gains that can be made by observing galaxies in the near-infrared. Overall, $\sim 70\%$ of the galaxies observed show evidence for a bar at 2.1μm.

3. The Incidence of Bars in Seyfert and Normal Galaxies

Figure 1 summarizes the bar statistics in Paper I. We note that the percentage of barred systems is comparable in the Seyfert and normal galaxy samples. This suggests that Seyfert nuclei do not occur preferentially in barred galaxies, a result consistent with earlier studies at optical wavelengths (Heckman 1980; Simkin, Su, & Schwarz 1980; Moles et al. 1995). A slightly higher percentage of the Seyfert 2 galaxies than Seyfert 1 galaxies appear to be barred in our images (83% vs. 67%, respectively), but this result is not statistically significant given the small number of objects of each type.

While we find no significant difference between the percentage of barred galaxies in our normal and active galaxy samples, there may still be differences between the Seyfert hosts and spiral galaxies in general. For example, in selecting our control sample, we have matched the normal galaxies to the Seyfert galaxies in total blue luminosity. However, the Seyfert host galaxies tend to be more luminous on average than the typical spiral galaxy in the RSA catalog. Thus, our control galaxies are more luminous in the blue than typical RSA spirals and our results for the control sample may not reflect the characteristics of typical spirals. In fact, we note that the percentage of bars in both the Seyfert and control sample is higher in the RSA (i.e. 42% and 45%) than the overall percentage of barred galaxies in the RSA for similar Hubble types (for example, only 25% of the RSA spirals of type Sa or Sab are barred). Therefore there may be a trend between the luminosity of the host and the presence of a bar. While ideally we would like to make a direct comparison between the bar properties of our Seyfert galaxies and the RSA spirals in general, near-infrared images for large samples of spirals over a range in luminosities do not yet exist. From the present data, we can conclude that the percentage of barred galaxies is comparable among Seyfert galaxies and normal spiral galaxies of similar luminosity.

4. Bars As A Fueling Mechanism

Shlosman, Frank & Begelman (1989) have proposed a “bars within bars” mechanism that would drive material collected from a large-scale bar down to the scales where the

central supermassive blackhole dominates the gravitational potential ($\sim$ inner 10 pc). In their model, gas driven inward from the large-scale stellar bar accumulates in the central few hundred parsecs in a rapidly rotating disk. If the mass of the gas in this disk is an appreciable fraction ($> 20\%$) of the dynamical mass at that radius, the disk may become unstable and a gaseous bar can form. A dynamically unstable series of such bars may exist, continuing the inflow of material towards the nucleus.

Nested bars have been observed in some galaxies (e.g. Shaw et al. 1995; Wozniak et al. 1995; Friedli et al. 1996), possibly supporting the above scenario. In fact, Wozniak et al. (1995) have noted a high percentage of Seyfert galaxies in their sample of double-barred systems. We have searched for the presence of multiple bar structures in our near-infrared images. Figure 1 shows, however, that the percentage of double-barred galaxies is actually higher in our normal galaxy sample than in our Seyfert sample. The failure to find multiple bars in most of our galaxies could be a result of our limited resolution. At the typical distance of our sample galaxies, our spatial resolution is $\sim$ 300–500 pc ($H_o = 50$ km s^{-1} Mpc^{-1} assumed). Higher resolution images may uncover many more examples of multiple bars. We also note that the "bars within bars" mechanism proposed by Shlosman et al. (1989) relies on *gaseous* bars in the inner kiloparsec and these bars may not always be accompanied by the stellar bars that our images probe. High resolution observations of atomic and molecular gas in Seyferts may be required to fully test the Shlosman et al. (1989) scenario.

Piner, Stone & Teuben (1995) have recently suggested that bars with a high axial ratio (i.e. thin bars) can also move mass efficiently into the inner 100 pc of a galaxy. A comparison of the maximum ellipticity for the bars in the two samples (Figure 2) suggests no differences in the bar axial ratios of the Seyfert and normal galaxies. Furthermore, the two galaxies with the highest bar axial ratios are normal galaxies. Thus, we find no evidence that Seyfert galaxies preferentially contain thin bars.

5. Non-Barred Seyferts

While bars appear to be a common feature in Seyfert galaxies, $\sim$ 30% of our sample galaxies show no evidence for a bar even in the near-infrared. It seems likely that most of these galaxies do not contain bars. A particularly striking example is the Seyfert 1 galaxy NGC 7213, which has nearly circular isophotes from the center down to a surface brightness level of $\sim$ 19 K mag arcsecond^{-2}. The failure to find bars in even this small percentage of Seyferts indicates that bars are probably not a ubiquitous feature of active galaxy hosts. Mcleod & Reike (1995) reached a similar conclusion from their K-band study of the CfA

Seyfert sample.

A relevant question is whether the non-barred Seyferts show evidence for other perturbations that might be responsible for fueling the nuclear activity. Galaxy interactions and encounters have often been suggested as a mechanism to induce activity in galaxies and in fact several of the non-barred Seyferts appear to be interacting with neighboring galaxies (e.g. NGC 5427; Kennicutt & Keel 1984). However, in other cases, the nearest neighbor is much too far away for gravitational interactions to be a reasonable scenario (e.g. NGC 788 nearest neighbor is over 1 h_{50} Mpc away; Moles et al. 1995). In addition, when a major merger interaction drives gas toward the center of a galaxy it does so by forming a bar (Mihos & Hernquist 1996). Since these possibly interacting Seyferts are non-barred, it is not clear how the interaction could be transporting mass to the central engine.

Moles et al. (1995) have suggested that although bars may not be more common in Seyfert galaxies than normal spirals, other features often associated with bars, such as rings, may be more prevalent in galaxies with nuclear activity. However, rings are a secondary probe of the potential and not as straightforward a probe as our near-infrared images. Thus, a non-detection of a bar in the near-infrared probably rules out the presence of a strong nonaxisymmetric component to the potential even when the galaxy has a ring.

6. Destruction of Bars in Active Galaxies

It has been proposed that the formation of a black hole at the center of a galaxy can lead to the destruction of a bar (Norman et al. 1996; Friedli & Benz 1993). The simulations of Norman et al. (1996) show that the bar can be destroyed in only a fraction of the bar rotation time once the mass of the central black hole approaches 5% of the total mass of the galaxy. For most barred galaxies this means that bars can be destroyed in only $\sim 10^7$ years. In this case, the stars that made up the bar are distributed into random axisymmetric orbits that give the appearance of a bulge. This very fast destruction time scale means that it may be possible for a black hole at the center of a galaxy to remain active even if the bar that supplied the fuel has been destroyed.

These non-barred Seyferts should exhibit certain characteristics if they are formerly barred galaxies. The stellar population of the bulge of these galaxies should be the same age as the stellar population of the disk. In addition, the central velocity dispersion of these galaxies should be quite high since the central black hole should contain $\sim$5% of the total mass of the galaxy. Therefore, the velocity dispersion of the centers of the non-barred Seyferts should imply a higher mass fraction in the central region than the

velocity dispersions of the central regions of the barred Seyfert galaxies, where the ratio of black hole to galaxy mass is presumably lower.

7. Conclusions

We have used a large near-infrared imaging survey to study the bar properties of Seyfert and normal galaxies. We find near-infrared bars in all of the sample galaxies previously classified as barred in the Revised Shapely-Ames catalog and in $\sim 55\%$ of the galaxies previously classified as unbarred. Approximately 70% of the Seyfert galaxies are barred, with $\sim 10\%$ having multiple-bar structures. The percentage of bars is comparable in the normal galaxy sample. In general, the global properties of bars, such as axial ratio, appear to be similar in Seyfert and normal spiral galaxies of similar luminosity.

A significant fraction of the Seyferts studied show no evidence for bars even in the near-infrared. This suggests that either large-scale bars are not a universal mechanism for the transfer of mass to the central engine or that the bars in the observed non-barred Seyferts were destroyed, possibly with the formation of the central black hole.

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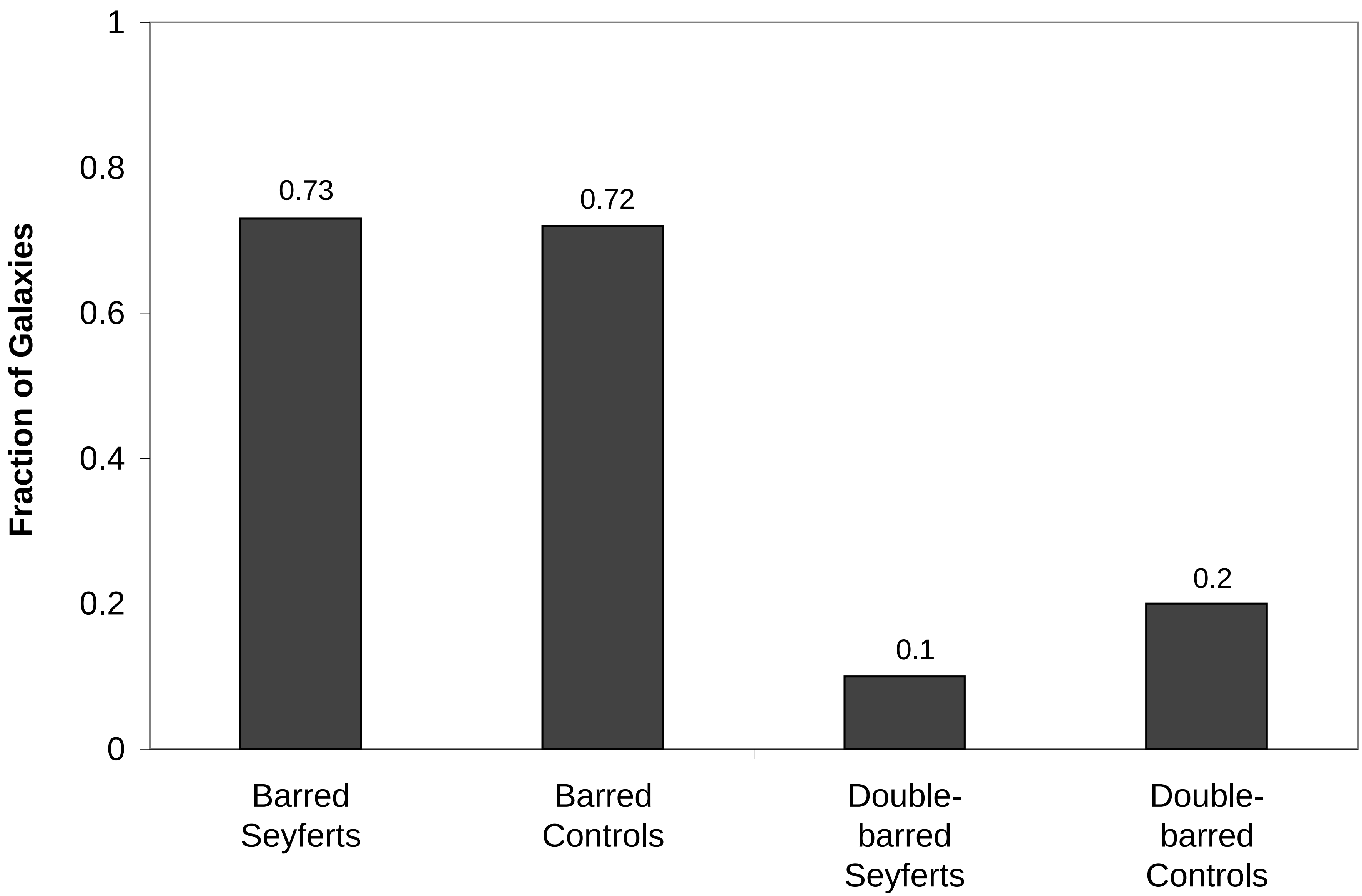
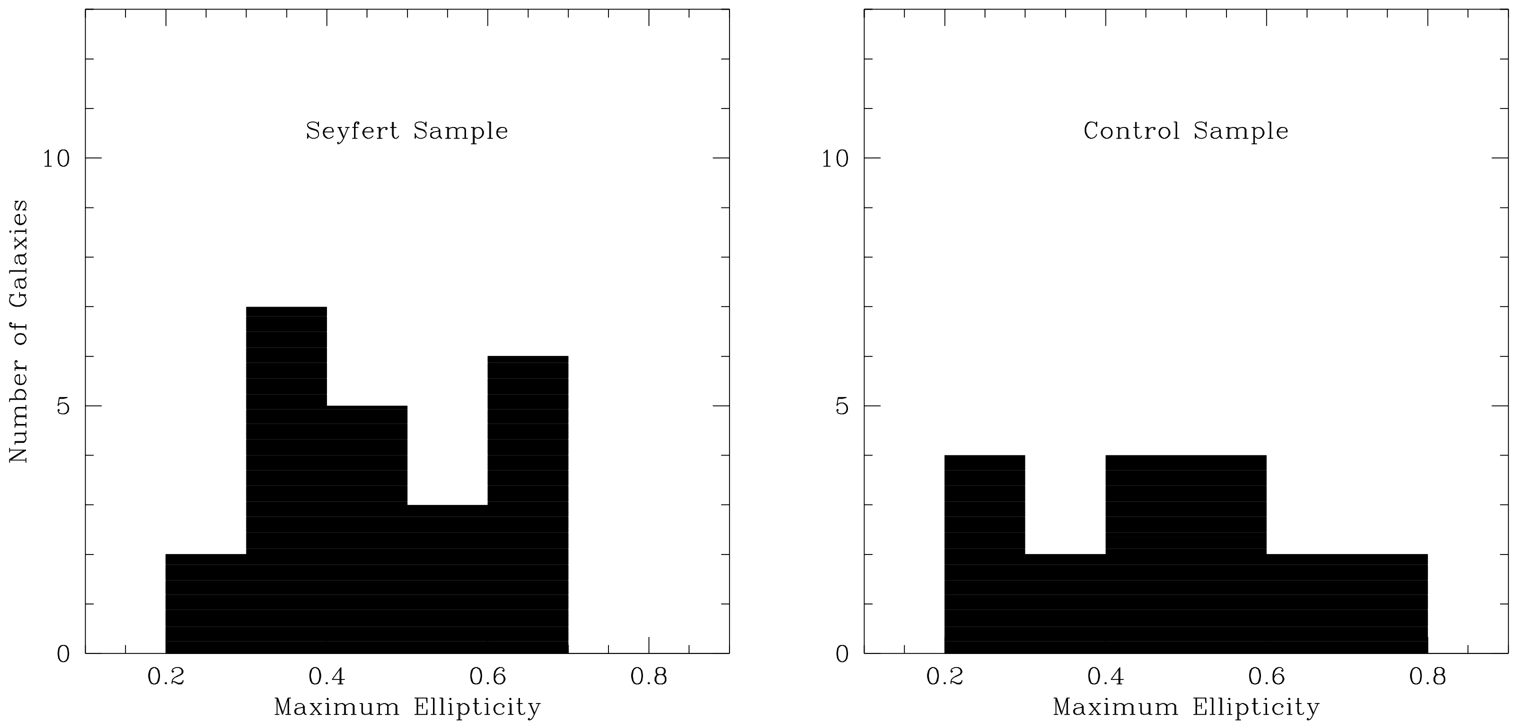
Figure Captions

Figure 1–Fraction of barred and double-barred systems in the Seyfert and control galaxy samples. The percentage of barred galaxies is comparable in the Seyfert and control samples. A slightly higher percentage of the normal galaxies have double bars.

Figure 2–Histogram of the maximum ellipticities for the bars in the Seyfert and control galaxy samples. There is no evidence that the bars in Seyferts are preferentially thin (i.e. high ellipticity).



Fraction of Galaxies
1
0.8
0.6
0.4
0.2
0
0.73
0.72
0.1
0.2
Barred Seyferts
Barred Controls
Double-barred Seyferts
Double-barred Controls


Seyfert Sample
Control Sample
Number of Galaxies
Maximum Ellipticity
Maximum Ellipticity
0
5
10
0.2
0.4
0.6
0.8